

RECYCLE OF CONTAMINATED/USED CONCRETE USING CEMENT-LOCK™ TECHNOLOGY

FINAL REPORT
(October 1996-March 1997)

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16. Abstract (Limit: 200 words) <p>The Cement-Lock Technology, developed by the Institute of Gas Technology (IGT), offers a one-step solution for treating various types of contaminated materials. In the process, organic contaminants are completely destroyed, inorganic contaminants are immobilized, and the resultant solid product is converted to cement for sale in the marketplace. Implementing this technology would significantly increase the use of natural gas.</p> <p>In the current program, several bench-scale tests were conducted in which aged siliceous (silica-based aggregate) concrete was treated by this technology. The concrete was mixed with different amounts of inexpensive modifiers and melted at about 2300°F. The melt was then rapidly quenched with water to retain the desired amorphous phase with the latent cementitious properties. In one test, the concrete was contaminated with 5000 ppm of oil and 500 ppm of chromium. The amorphous material produced was then converted to blended cement per ASTM procedures.</p> <p>The organic destruction in excess of 99.9% was achieved in the ground melt. Per the EPA TCLP procedure, the chromium leachability of the blended cement was only 0.097 mg/L in the leachate (the regulatory leachability limit is 5 mg/L). The 3, 7, and 28-day compressive strengths of the blended cement were 2530, 3370, and 5475 psi, respectively; these strengths significantly exceed ASTM C 595 and ASTM C 1157 requirements.</p> <p>Two bench-scale tests using a calcareous (limestone-based) concrete were also conducted. The melts produced were determined to be amorphous in nature and suitable for producing blended cement.</p>				
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EXECUTIVE SUMMARY

This report presents the results of an experimental program conducted by the Institute of Gas Technology (IGT) under a contract with the Gas Research Institute (GRI) for "Recycle of Contaminated/Used Concrete Using Cement-Lock™ Technology". The overall objective of the program was to determine the technical feasibility of applying IGT's Cement-Lock Technology for converting contaminated/used concrete into a valuable blended cement product, while treating the contaminants present therein. Construction Technology Laboratories, Inc. (research arm of the Portland Cement Association) was a subcontractor to IGT on the program. The experimental work was conducted during the period from October 1996 through March 1997.

The Cement-Lock Technology, developed by IGT, offers a one-step solution for treating various types of contaminated materials in which the organic contaminants are completely destroyed, inorganic contaminants are immobilized, and the resultant solid product can be put to a beneficial use (Business Week, 1997; Baker, 1997). The technology is flexible enough to accommodate the complex and varying nature and levels of contaminants and their widespread spatial distribution in the contaminated material. The technology is capable of simultaneously handling the fixation of heavy metals and the destruction of polynuclear aromatic hydrocarbons (PAHs) and organochlorines such as dioxins, furans, polychlorinated biphenyls (PCBs), chlorinated pesticides, and herbicides. Natural gas is the most suitable source of energy for this recycle and reuse technology. About 11 BCF of natural gas is required to process one million tons of concrete.

Several bench-scale tests were conducted in this program in which aged siliceous (silica-based aggregate) concrete was mixed with different amounts of inexpensive modifiers and melted in a muffle furnace at a temperature of about 2300°F. The melt was then withdrawn from the furnace and quickly quenched in cold water to retain the amorphous phase and prevent crystallization. The melt product (Ecomelt™) with latent cementitious properties was dried in air. A microscopic evaluation confirmed that the Ecomelt was amorphous in nature. In another test, 5000 ppm of oil and 500 ppm of chromium (these quantities exceed the expected concentrations in the contaminated/used concrete) were added as contaminants to one of the

formulations, and the test was repeated. The Ecomelt produced in this test was dried in air and then used to prepare blended cement per ASTM specifications. Several mortar cubes were prepared using the blended cement for compressive strength determination.

Two bench-scale tests were also conducted using an aged calcareous (limestone-based aggregate) concrete. The melts produced were determined to be amorphous in nature, and suitable for producing blended cement.

The results obtained from the bench-scale experimental study conducted in this program are summarized below:

- The Cement-Lock Technology is suitable for treating contaminated siliceous as well as calcareous concrete due to its wide operating window in terms of temperature and quantity of modifiers needed. The quantity of modifiers required for this particular application is less than thirty weight percent of concrete.
- The organic contaminant (oil) present in the concrete was destroyed in the process.
- The total chromium present in the blended cement was 380 mg/kg (ppm). The EPA TCLP procedure conducted on the blended cement showed the amount leached from the blended cement was only 0.097 mg/L in the leachate, which is significantly below the regulatory limit of 5 mg/L for chromium. This demonstrates that the metals present in the contaminated concrete can be immobilized in the final product.
- The blended cement produced from the contaminated concrete and modifiers generated 3, 7, and 28-day compressive strengths greater than those required for general purpose cement. The 28-day strength is about 57 percent higher than the ASTM requirement. It is significant to note that activators (performance enhancing additives) were not added to the blended cement product.

The Cement-Lock Technology is now ready for a pilot-scale demonstration with contaminated concrete. Previous studies conducted at IGT with dredged estuarine sediments at bench-scale and pilot-scale levels had yielded similar results in terms of organic destruction, metals immobilization, and cement quality. Results from the pilot-scale operation with concrete are also expected to be similar to those achieved in the bench-scale testing.

The Cement-Lock process economics are also very favorable because of the dual revenue streams associated with the process: processing (tipping) fees received for the contaminated concrete and revenues received from the sale of the cement product. The next step is to identify

a commercialization team consisting of an A&E company, an equipment manufacturer, a cement company, a gas company, and private investors.

TABLE OF CONTENTS

	<u>Page</u>
INTRODUCTION	1
Background	1
Program Objective	3
Program Success Criteria	3
CEMENT-LOCK TECHNOLOGY DESCRIPTION, BENEFITS, AND LIMITATIONS	5
BENCH-SCALE TREATMENT OF CONCRETE	11
Concrete Characterization	11
Chemical Analysis	11
X-Ray Diffraction	11
Bench-Scale Production of Blended Cement from Concrete	15
Raw-Mix Formulation	15
Ecomelt Production	15
Determination of Amorphous Phase in Ecomelt	15
Production of Blended Cement	16
Test Details	16
Testing and Evaluation of Blended Cement	22
Organic (Oil) Destruction	22
Metal Immobilization	22
Compressive Strength	22
ACHIEVEMENT OF PROGRAM SUCCESS CRITERIA	25
IMPACT OF TECHNOLOGY SCALE-UP ON DESTRUCTION AND REMOVAL EFFICIENCY	27
ENVIRONMENTAL IMPACT	31
TRANSITION OF TECHNOLOGY FROM BENCH-SCALE TO FULL-SCALE OPERATION	33
Description of Pilot-Scale Facility	33
Existing/Operating Large-Scale Facilities	37

TABLE OF CONTENTS (Cont.)

	<u>Page</u>
COMMERCIALIZATION OF CEMENT-LOCK TECHNOLOGY	45
CONCLUSIONS AND RECOMMENDATIONS	49
Conclusions	49
Recommendations for Further Work	50
ACKNOWLEDGMENTS	51
BIBLIOGRAPHY	53

LIST OF FIGURES

<u>Figure No.</u>		<u>Page</u>
1	Demand and Production of Cement in the United States	2
2	Cement-Lock = Manufacturing Process	6
3	Cement-Lock Technology Schematic Diagram for Processing Contaminated Concrete	7
4	XRD Pattern of Siliceous Concrete Showing Presence of Various Crystalline Phases	13
5	XRD Pattern of Ecomelt Showing Amorphous Phase	20
6	Process Flow Diagram of Cement-Lock Pilot Plant	34

LIST OF TABLES

<u>Table No.</u>		<u>Page</u>
1	Primary Feedstock Candidates for Cement-Lock Technology	9
2	Secondary Feedstock Candidates for Cement-Lock Technology	10
3	Major/Minor Oxide Composition of Concretes Tested	12
4	Summary of Test Results	17
5	Metal Immobilization in Blended Cement Produced From Concrete	23
6	Compressive Strength of Blended Cement Produced From Concrete	24
7	Comparison of Organic Destruction in Bench-Scale and Pilot-Scale Units for Dredged Estuarine Sediments	28
8	Comparison of TCLP Results on Blended Cement Produced in Bench-Scale and Pilot-Scale Units from Dredged Estuarine Sediments	28
9	Comparison of Compressive Strength of Blended Cement Produced in Bench-Scale and Pilot-Scale Units from Dredged Estuarine Sediments	29
10	Fate of Concrete Contaminants in Cement-Lock Process	32
11	Commercial Experience with Type "A" Ecomelt Generator	38
12	Raymond™ Rotary Kiln Systems	39
13	Svedala Rotary Kiln Systems	43
14	Commercialized IGT Technologies	47

INTRODUCTION

Background

Currently, much of the used concrete that is recovered from building demolition or road reconstruction is disposed of in landfills. Less than 20 percent can be recycled as aggregate. Very large tonnages of concrete recovered from many different kinds of facilities are contaminated with hazardous organic and/or inorganic materials, which can not be recycled. The cost of disposal of these materials - the tipping fee - ranges from \$60 to \$200 per ton. In comparison, the tipping fee for everyday trash disposal ranges from about \$5 to \$15 per ton depending upon geographic location (excluding transportation costs). A further complicating factor is that capacity at existing landfills is diminishing and new landfills are difficult to site. In its FY 1997 Congressional Budget Request, the U.S. government indicated that it has over 66,000,000 cubic yards of contaminated soils and concrete that require remediation. Although no survey is available for the private sector (industrial sites, old concrete from roads, landfills, bridges, etc.), it is not inconceivable that this volume is easily ten times that reported by the U.S. government.

The Cement-Lock™ Technology, developed by the Institute of Gas Technology (IGT), offers a one-step solution for treating contaminated materials in which the organic contaminants are completely destroyed, inorganic contaminants are immobilized, and the resultant solid product from the treatment is put to a beneficial use (Business Week, 1997; Baker, 1997). The technology is flexible enough to accommodate the complex and varying nature and levels of contaminants and their widespread spatial distribution. The Cement-Lock Technology is capable of simultaneously handling the fixation of heavy metals, and the destruction of polynuclear aromatic hydrocarbons (PAHs) and organochlorines, such as dioxins, furans, polychlorinated biphenyls (PCBs), chlorinated pesticides, and herbicides. Natural gas is the most suitable source of energy for this recycle and reuse technology. About 11 BCF of natural gas is required to process one million tons of concrete. As a beneficial use, Cement-Lock Technology produces cement from contaminated concrete for sale in the merchants market. Cement was selected as a beneficial-use product due to the reasons stated below.

The decline in the infrastructure of the U.S. cement industry is well documented. The United States has gone from being a cement exporting nation in the 60's to a cement importing nation in the 90's due to increasing demand for cement by the construction industry (Figure 1). Demand is rising by an average of about one percent per year – or about 800 thousand metric tons. U.S. production, however, has not kept pace with demand. In 1996, the U.S. cement shortfall was about 15.8 million tons. At this rate of cement demand increase, the cement shortfall in the United States will be well over 150 million tons in the next decade.

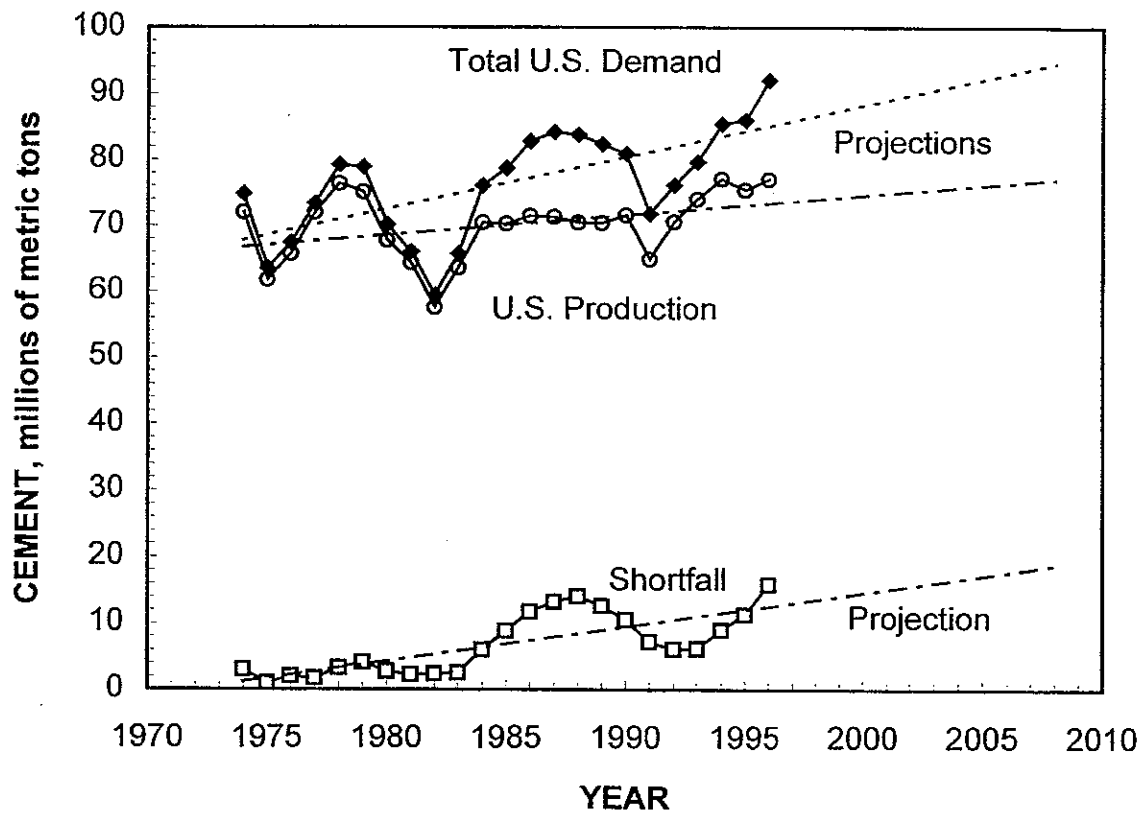


Figure 1. DEMAND AND PRODUCTION OF CEMENT IN THE UNITED STATES

New cement manufacturing capacity is being added slowly. About 70% of U.S. cement manufacturing facilities are over 25 years old. Exorbitant construction costs, environmental regulations, and increased cost of raw materials and energy – compounded by stagnant cement prices due to imports – are major reasons for the stifled growth in the cement industry. Conditions are not expected to improve until new and innovative ideas are implemented that provide attractive returns for manufacturers.

The Cement-Lock Technology offers an outstanding solution to revitalize the cement industry infrastructure at a fraction of the capital cost, while utilizing raw materials and wastes that actually generate revenues from their use. Thus, a supplemental cement supply can be produced and sold at prices comparable to or less than those of the conventional portland cement.

Program Objective

The overall objective of the program was to determine the technical feasibility of applying IGT's Cement-Lock Technology to the conversion of contaminated/used concrete into a valuable blended cement product.

Program Success Criteria

The following criteria were established to measure the success of this research program:

- Contaminated concrete to be treated by the Cement-Lock Technology (to destroy organics and immobilize metals) must not consume fresh modifiers more than 50 weight percent of concrete
- Blended cement produced from contaminated concrete must pass the EPA TCLP test for appropriate priority metals
- Compressive strength of blended cement produced from contaminated concrete must pass ASTM standards for blended cement.

This report presents the results of an experimental program conducted by IGT under a contract with GRI for "Recycle of Contaminated/Used Concrete Using Cement-Lock

Technology.” Construction Technology Laboratories, Inc. (CTL, Skokie, IL - the research arm of the Portland Cement Association) was a subcontractor to IGT on the project. CTL performed standard compressive strength tests on the Cement-Lock end product. The experimental work was conducted during the period from October 1996 through March 1997.

CEMENT-LOCK TECHNOLOGY DESCRIPTION, BENEFITS, AND LIMITATIONS

The Cement-Lock Technology is an advanced management system for contaminated soils, sediments, sludges, concrete and building debris, and similar wastes. This technology systematically puts every ounce of waste to beneficial use. The Cement-Lock Technology converts the waste into a construction-grade blended cement, which can be sold in the open market. All secondary and fugitive waste streams associated with typical waste processing are completely eliminated. Additional beneficial products that could be produced depend upon the waste stream and its composition. In the case of recycled concrete, in addition to producing blended cement, it could also produce steam for power generation.

The beneficial reuse of wastes through Cement-Lock Technology application adds many advantages to conventional waste processing. These include: a) additional revenues generated from the sale of blended cement; b) savings from the elimination of the need to landfill the wastes, including sizable quantities of residues from conventional processing; c) ability to maintain extremely low tipping fees because of secondary revenue streams; and d) environmental superiority when compared to any conventional processing.

The Cement-Lock Technology is not to be confused with either the cement manufacturing plants or incineration technologies. With only the final product as a common element, the Cement-Lock Technology bears no other relationship to the manufacture of portland cement. The Cement-Lock plant is considerably simpler than a portland cement manufacturing plant and bears little or no resemblance to the actual complex cement plant. Unlike a cement plant, the Cement-Lock Technology does not have an extensive sizing requirement for the materials being processed, it does not have the extreme temperature requirements of a cement plant, it does not produce any waste stream (such as cement kiln dust), it does not require complex energy management to save energy, it does not produce high NO_x emissions, it does not have stringent requirements for materials of construction, and finally the starting raw materials are entirely different.

Nor is the Cement-Lock Technology an incineration process either. It is rather a thermo-chemical manufacturing process that utilizes inherent properties of wastes as feedstocks for producing economically attractive end products (Figure 2).

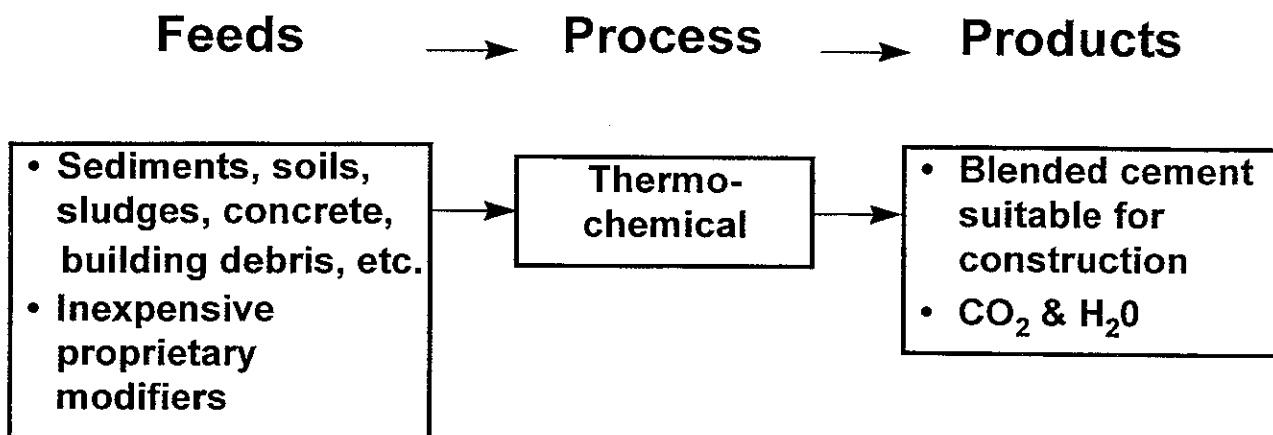


Figure 2. CEMENT-LOCK = MANUFACTURING PROCESS

In the Cement-Lock Technology (Figure 3) contaminated concrete is reacted in a melter with suitable modifiers in proportions required for producing an environmentally friendly material called Ecomelt™. Ecomelt is a decontaminated and environmentally stabilized product that possesses latent cementitious properties. These properties are utilized to convert the Ecomelt into blended cement, which has compressive strength properties exceeding those required for conventional portland cement. The quantity of modifiers, which depends upon the contaminated/used concrete composition, is typically less than thirty weight percent of the concrete. The melter for carrying out this process is operated at temperatures up to about 2550°F (1399°C), or lower temperatures sufficient to melt the concrete-modifier mixture. In the presence of excess air at these temperatures, organic contaminants originally present in the concrete are completely destroyed and converted to innocuous carbon dioxide and water.

Chlorine present in some of the organic compounds (such as dioxins, furans, and PCBs) is converted to hydrogen chloride (HCl), which is either sequestered in the melt or readily scrubbed from the flue gas by using a solid media filter comprised of calcium oxide operating at 1000° to 1100°F (538° to 593°C).

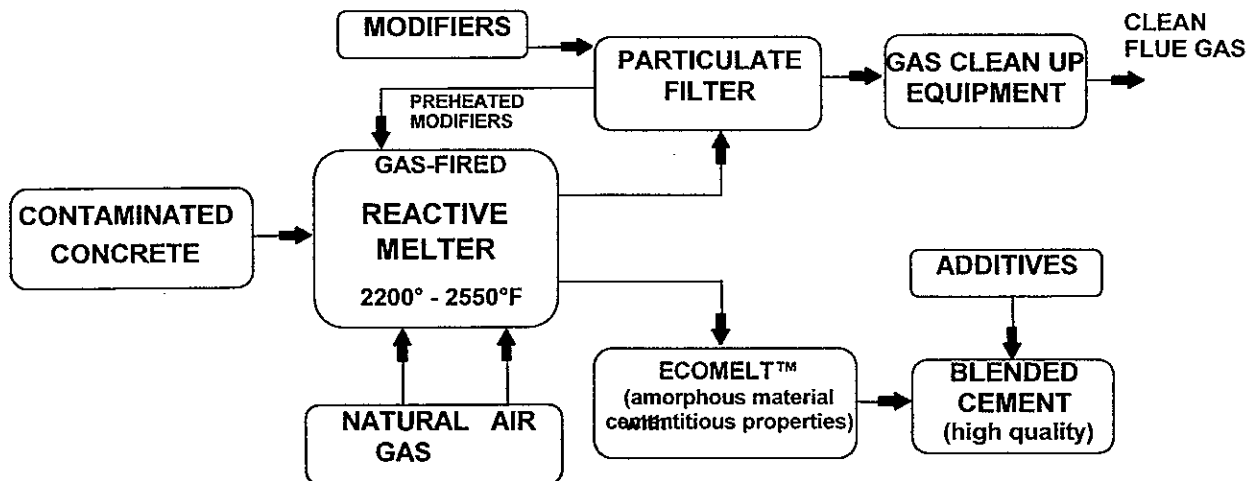


Figure 3. CEMENT-LOCK TECHNOLOGY SCHEMATIC DIAGRAM FOR PROCESSING CONTAMINATED CONCRETE

Heavy metals present in the concrete are locked into the cement matrix (predominantly calcium-alumino silicates) to completely immobilize them. The melt containing immobilized metals is rapidly quenched to prevent crystallization and subsequently pulverized and mixed with an additive to yield blended cement. This product can be put to beneficial use in the construction industry with a ready market. Volatilized heavy metals as well as non-destroyed organics are recovered from the gas and recycled to the melter for complete assimilation in the process. Highly volatile metals, such as mercury and arsenic, are removed from the off-gas by amalgamating them with affinity metals distributed over a filter element.

Hot flue gas emanating from the melter is used to preheat the modifiers before they enter the melter. The modifiers also act as a filter to remove particulates from the flue gas. The flue

gas is quickly cooled from about 2550° to 1600°F (1399° to 871°C) in the filter. Additional heat can be recuperated from the flue gas to raise steam.

The Cement-Lock Technology does not generate any secondary hazardous waste streams. The streams exiting the process are: 1) blended cement as a primary product, 2) a solid stream consisting of CaCl_2 and CaSO_4 (with small amounts of NaCl and KCl) as a secondary product usable as winter road salt, 3) CO_2 and water vapor, and 4) an amalgam of Hg as a useful secondary resource for recovery of Hg.

The advantages of the Cement-Lock Technology include:

- a. It can treat all types of contaminated (organic as well as inorganic) concrete, regardless of its concentration.
- b. No feed pretreatment is required.
- c. No secondary hazardous waste streams are generated from the process.
- d. It is an environmentally friendly technology.
- e. It is a simple - yet effective process.

The following benefits accrue from deployment of the Cement-Lock Technology:

- It provides a sound basis for destroying harmful organic contaminants and immobilizing inorganic contaminants present in concrete.
- It utilizes concrete to produce a widely used salable product (blended cement) thereby conserving land-based resources which would have otherwise been deployed.
- It helps defray the costs of concrete cleanup whereby resources could be deployed elsewhere for environmental restoration.
- It does not discharge environmentally harmful pollutants into the atmosphere.
- The product from concrete treatment is environmentally safe to use in the construction industry.
- Although the technology is thermo-chemical in nature, it offers much superior destruction of organic contaminants than any known incineration technology.

The Cement-Lock Technology can also be applied to remediation of contaminated sediments, and contaminated soils at Superfund sites as well as manufactured gas plant sites. Besides cleaning up waste sites, the technology offers a great potential for additional job creation and economic enrichment in affected communities.

The technology has no known limitation in terms of application with respect to types of contaminants or the levels of contaminants. It has no limitations on water content of the waste stream either.

The Cement-Lock Technology can handle a variety of feedstocks; these feedstocks are summarized in Tables 1 and 2. Primary feedstocks (Table 1) include concrete, sediments, soils, sludges, fly ash, bottom ash, cement kiln dust, etc. Secondary feedstocks (Table 2), such as petroleum coke, used rubber tires, refinery bottoms, paper mill sludge, etc., contain fuel value and can be co-processed with primary feedstocks.

Table 1. PRIMARY FEEDSTOCK CANDIDATES FOR CEMENT-LOCK TECHNOLOGY

Feedstock	Category	Water Content Limit, wt %	Limit on Type and Extent of Organic Contaminants	Limit on Type and Extent of Inorganic Contaminants
Contaminated concrete from DOE and DOD decommissioning	Hazardous	n/a	None	None
Construction debris	Hazardous	n/a	None	None
Dredged estuarine sediments, Cat. I, II, III	Nonhazardous	Up to 70%	None	None
Contaminated soil from Superfund sites	Hazardous	n/a	None	None
Contaminated soil from town gas sites	Nonhazardous	n/a	None	n/a
Sludge from Superfund sites	Hazardous	Up to 70%	None	None
PCB-Contaminated sediments	Hazardous	Up to 70%	None	n/a
Fly ash and bottom ash	Hazardous & Nonhazardous	n/a	n/a	None
Spent FCC catalyst	Hazardous	n/a	None	None
Cement kiln dust	Hazardous	n/a	n/a	None

**Table 2. SECONDARY FEEDSTOCK CANDIDATES FOR
CEMENT-LOCK TECHNOLOGY**

Waste Stream	Category	Reason for Being a Waste Stream	Limit on Organic Contaminants for Cement-Lock Application	Limit on Inorganic Contaminants for Cement-Lock Application
Used rubber tires	Nonhazardous	Difficult to burn in combustion systems, produces dioxins, furans, SO _x , etc.	None	None
Municipal sewage sludge	Hazardous	High metal content	None	None
PCB-Contaminated transformer oils	Hazardous	PCB content	None	n/a
Refinery bottoms	Nonhazardous	High sulfur and metals	None	None
Petroleum coke	Nonhazardous	High sulfur and vanadium	None	None
Coal washings (Culm)	Nonhazardous	High sulfur, high ash	None	None
Paper mill sludges	Hazardous	Dioxins	None	None
Gas from sewage treatment plant	Nonhazardous	high sulfur, low calorific value	None	n/a
Waste organic stream from chemical plant	Hazardous & Nonhazardous	Difficult to dispose	None	None

BENCH-SCALE TREATMENT OF CONCRETE

This section describes characteristics of the concretes tested, details of the bench-scale experimental program conducted, and testing and evaluation of the Cement-Lock end product, namely, blended cement.

Concrete Characterization

Two types of aged concretes were tested in this program.

1. Siliceous concrete - gravel/silica-based concrete
2. Calcareous concrete - crushed limestone-based concrete

These concrete samples were 18-years and 5-years old, respectively. The concrete samples were finely ground (about 90 percent through 100 mesh) using a primary crusher and then a ball mill. The siliceous concrete contained siliceous aggregate whereas the calcareous concrete contained crushed limestone aggregate.

Chemical Analysis

The concrete samples were ground to pass 100 mesh, and analyzed by x-ray fluorescence (XRF) spectrometry for their chemical compositions. The analyses, expressed as oxides, are given in Table 3. The siliceous concrete contained 69.89% SiO_2 , 7.71% Al_2O_3 , 10.46% CaO , and 2.66% Fe_2O_3 . The calcareous concrete contained 27.33% SiO_2 , 3.16% Al_2O_3 , 29.19% CaO , and 1.79% Fe_2O_3 . The siliceous concrete is rich in silica (69.89% vs. 27.33%), whereas the calcareous concrete is rich in CaO (29.19% vs. 10.46%). Also, loss-on-ignition (LOI) of the calcareous concrete was significantly higher (27.95% vs. 4.26%) due to evolution of CO_2 from the limestone (CaCO_3) aggregate.

X-Ray Diffraction

An XRD (x-ray diffraction) of the siliceous concrete is shown in Figure 4. The XRD shows several peaks, indicating the presence of several crystalline compounds in this material. These crystalline phases are non-reactive and can only act as fillers when used with cement.

Thermo-chemical treatment by Cement-Lock Technology converts these phases to reactive amorphous components which are capable of forming a complementary cementitious phase – calcium-silicate-hydrate – when blended with portland cement and hydrated with water.

Table 3. MAJOR/MINOR OXIDE COMPOSITION OF CONCRETES TESTED

<u>Specie</u>	<u>Siliceous Concrete</u>	<u>Calcareous Concrete</u>
	----- wt % -----	
SiO ₂	69.89	27.33
Al ₂ O ₃	7.71	3.16
Fe ₂ O ₃	2.66	1.79
CaO	10.46	29.19
MgO	0.52	8.15
SO ₃	0.30	1.28
Na ₂ O	1.33	0.20
K ₂ O	1.67	0.63
TiO ₂	0.28	0.18
P ₂ O ₅	0.11	0.06
Mn ₂ O ₃	0.08	0.04
SrO	0.07	0.04
LOI (950°C)	4.26	27.95
Others (by diff.)	<u>0.66</u>	<u>0.00</u>
Total	100.00	100.00

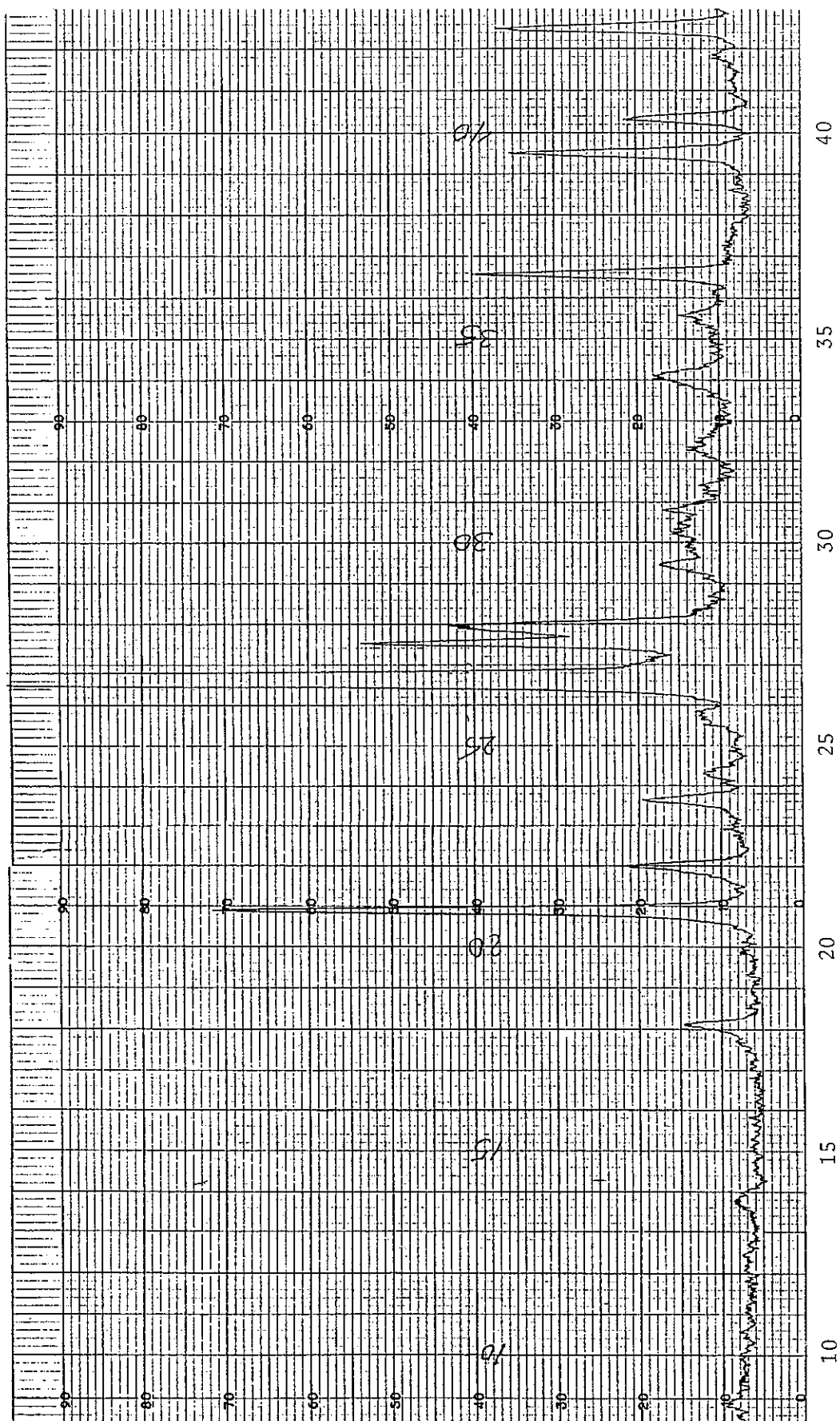


Figure 4, Part A. XRD PATTERN OF SILICEOUS CONCRETE SHOWING PRESENCE OF
VARIOUS CRYSTALLINE PHASES

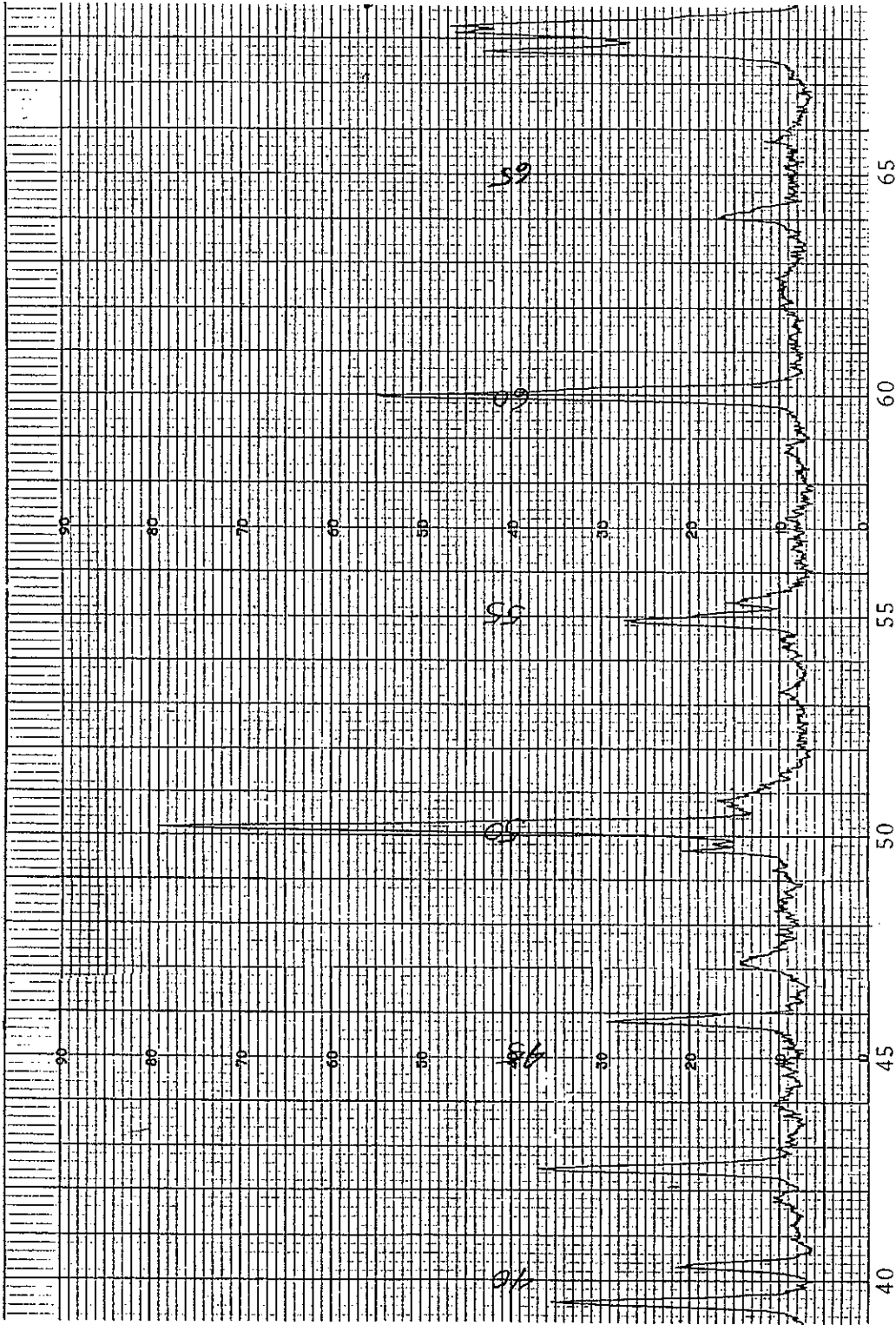


Figure 4, Part B. XRD PATTERN OF SILICEOUS CONCRETE SHOWING PRESENCE OF
VARIOUS CRYSTALLINE PHASES

Bench-Scale Production of Blended Cement From Concrete

The procedures used for conducting a bench-scale test and producing blended cement are described below.

Raw-Mix Formulation

Based on prior experience with estuarine sediments from the New York/New Jersey harbor, and the chemical composition and the physical characteristics of the concrete samples, several raw-mix formulations were developed for producing a material with latent cementitious properties (Ecomelt). The criteria for determining the raw-mix formulations were to -

- Maximize the use of concrete in the raw mix
- Minimize the use of modifiers
- Have a low melting point of the mixture
- Produce Ecomelt with high degree of amorphosity
- Produce Ecomelt with adequate latent cementitious properties.

Ecomelt Production

The mixture of concrete and modifiers was hand-mixed in a mortar and pestle, loaded into an Inconel crucible, and fired in a muffle furnace at a predetermined temperature for about one hour duration. The melt was then withdrawn from the furnace, and quickly quenched in cold water to maximize amorphosity and to prevent crystallization. The melt (referred to as Ecomelt) was dried in air.

One pound of siliceous concrete yields approximately one pound of Ecomelt.

Determination of Amorphous Phase in Ecomelt

The Ecomelt was finely ground and a small sample was mounted on a glass slide. The sample was examined under an optical microscope with transmitted light to determine the level of amorphosity. Under ordinary light, both amorphous as well as crystal phases are visible, however, under cross-polar light, the amorphous phase is not visible. The Ecomelt can also be examined for the amorphosity using x-ray diffraction (XRD) method.

Production of Blended Cement

In order to test the Ecomelt as a suitable component for blended cements, IGT opted to use ASTM (American Society for Testing and Materials) Standard C 595. This standard requires the Ecomelt to be blended with portland cement. Therefore, the Ecomelt was finely ground in a ball mill to a Blaine fineness of about 4500 cm²/g. The ground material was then blended with Type I portland cement in the proportion of 40% Ecomelt and 60% portland cement as specified for Type IP and P blended cement per ASTM C 595 specifications. Type IP is a portland-pozzolan cement used in concrete for general construction; Type P is a portland-pozzolan cement for concrete construction where high strength at early age is not required. Maximum use of the pozzolan (40% by mass as specified by ASTM C 595) was a deliberate effort to minimize the use of portland cement while still aiming for strength properties comparable to those of Type IP and P cement. No activator (performance enhancing additive) was used in the blends.

Test Details

A total of seven tests were conducted during this program; five tests with siliceous concrete and two tests with calcareous concrete. Furthermore, in one test with the siliceous concrete (Test 5), the concrete was contaminated with 5000 ppm (0.5 wt %) of oil and 500 ppm of chromium (Cr⁺³) prior to the testing. Table 4 summarizes the amount of modifiers used, operating temperature, and amorphosity of the Ecomelt produced from each of the tests.

Test 1 was conducted with the raw-mix formulation such that target composition of the Ecomelt was similar to that successfully tested in the laboratory under another program with estuarine sediments. The mixture consisted of 78.2% concrete and 21.8% modifiers. The mixture was melted and held in the furnace at 1220°C (2228°F), and then rapidly quenched in cold water. The rapid quenching is necessary to prevent formation of crystals in the solidified matrix (Ecomelt). The crystalline phase is non-reactive whereas the reactive amorphous phase is capable of forming a complementary cementitious phase – calcium-silicate-hydrate – when blended with cement and hydrated with water. The Ecomelt was finely ground and observed

Table 4. SUMMARY OF TEST RESULTS

Test No.	1	2	3	4	5	6	7
Concrete Type	----- Siliceous -----			----- Calcareous -----			
<u>Feed:</u>							
Concrete, %	78.2	78.2	71.2	71.2	78.2	55.6	79.0
Modifiers, %	21.8	21.8	28.8	28.8	21.8	44.4	21.0
Temperature, °C	1220	1260	1260	1300	1220	1220	1280
Temperature, °F	2228	2300	2300	2372	2228	2228	2336
Contaminants Added	No	No	No	No	Yes*	No	No
Amorphosity [†] , %	85-90	>95	85-90	85-90	85-90	80-85	>95

* Contaminants Added: 5000 ppm of oil and 500 ppm of chromium (III).

[†] Based on visual observation under cross-polar optical transmission microscope.

under optical microscope with transmitted light to determine the extent of amorphous phase. Under ordinary light, both amorphous as well as crystalline phases are visible, however, under cross-polar light, the amorphous phase is not visible. Observation under the microscope indicated that the sample was 85 to 90% amorphous. To determine the effect of temperature, Test 2 was conducted at a higher temperature of 1260°C (2300°F). Observation under the microscope, of the ground Ecomelt produced in this test, indicated that the sample was over 95% amorphous.

The next two tests were conducted with a different formulation and at two different temperatures. This formulation was developed to reduce viscosity of the melt. The mixture consisted of 71.2% concrete and 28.8% modifiers. During Test 3, the mixture was melted and held in the furnace at 1260°C (2300°F), and then rapidly quenched in cold water. The Ecomelt was finely ground and observed under optical microscope with transmitted light to determine the extent of amorphous phase. Observation under the microscope indicated that the sample was 85 to 90% amorphous. To determine the effect of temperature, next test (Test 4) was conducted at 1300°C (2372°F). Observation under the microscope, of the ground Ecomelt produced in this test, indicated similar results.

Thus all four tests produced Ecomelts consisting mostly of amorphous phase, and therefore suitable for producing blended cement. The first formulation (Tests 1 and 2) required 21.8% modifiers, while the second formulation (Tests 3 and 4) required 28.8% modifiers. The next test (Test 5) was conducted with contaminated concrete under conditions similar to those used for Test 1 (representing the lowest operating temperature and the minimum quantity of modifiers added). The concrete was contaminated with 500 ppm of chromium (Cr III; Cr_2O_3 was used for this purpose) and 5000 ppm (0.5 wt %) of oil (these amounts exceed the expected concentrations in contaminated concrete). Chromium was chosen for contamination since chromium leaches out relatively easily. The mixture consisted of 78.2% concrete and 21.8% modifiers. This mixture was melted and held in the furnace at 1220°C (2228°F), and then rapidly quenched in cold water. Observation of the ground Ecomelt under the microscope indicated that the sample was 85 to 90% amorphous. The Ecomelt was also examined for

amorphosity using the x-ray diffraction (XRD) method. The XRD of the sample (Figure 5) showed that it is mostly a noncrystalline material.

The Ecomelt was subsequently finely ground in a ball mill for producing blended cement. The ground material was blended with Type I portland cement in the 40:60 weight ratio to meet either of the Type IP/P blended cement specifications as per the ASTM C 595 and C 1157 standards. Maximum use of the Ecomelt (40% by mass as specified by ASTM C 595) was a deliberate effort to minimize the use of portland cement while still aiming for strength properties compared to those of Type IP/P cement for concrete in general construction. No activator (performance enhancing additive) was used in the blends. The blended cement was then evaluated for organic (oil) destruction, chromium leachability (TCLP), and compressive strengths; the results are described later.

Within the present budget, two tests were also conducted with an aged calcareous (crushed limestone aggregate) concrete (these tests were not included in the proposed program). The first raw-mix formulation was developed such that the resulting melt would have composition similar to that successfully tested in the laboratory with estuarine sediments as well as siliceous concrete (Tests 1, 2, and 5). The mixture consisted of 55.6% concrete and 44.4% modifiers. This mixture was melted and held in the furnace at 1220°C (2228°F), and then rapidly quenched in cold water (Test 6). The Ecomelt produced was finely ground and observed under optical microscope. Observation under the microscope indicated that the sample was 80 to 85% amorphous. A second raw-mix formulation with the potential of maximizing the concrete use and minimizing incorporation of the modifiers was determined. The formulation consisted of 79.0% concrete and 21.0% modifiers. This test (Test 7) was conducted at 1280°C (2336°F). Observation under the microscope, of the ground Ecomelt produced in this test, indicated that the sample was over 95% amorphous. Thus, the Ecomelt produced in this test was of better quality than that produced in Test 6, while the amount of modifiers used was significantly less (21.0% compared to 44.4 % for Test 6). The Ecomelt samples produced in both tests with the calcareous concrete are suitable for producing blended cement. These tests also demonstrate that the Cement-Lock process has a wide operating window.

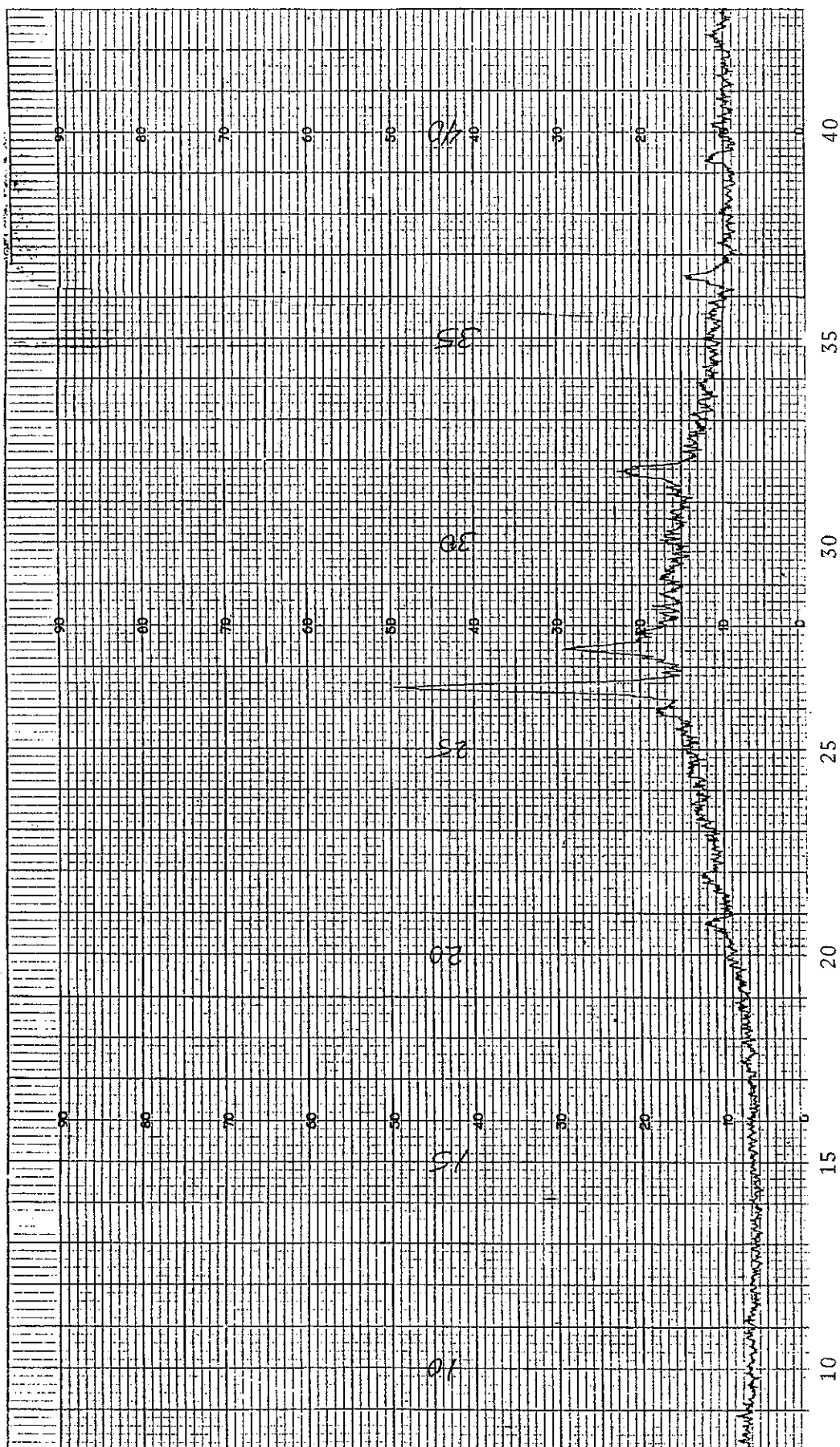


Figure 5, Part A. XRD PATTERN OF ECOMELT SHOWING AMPHOROUS PHASE

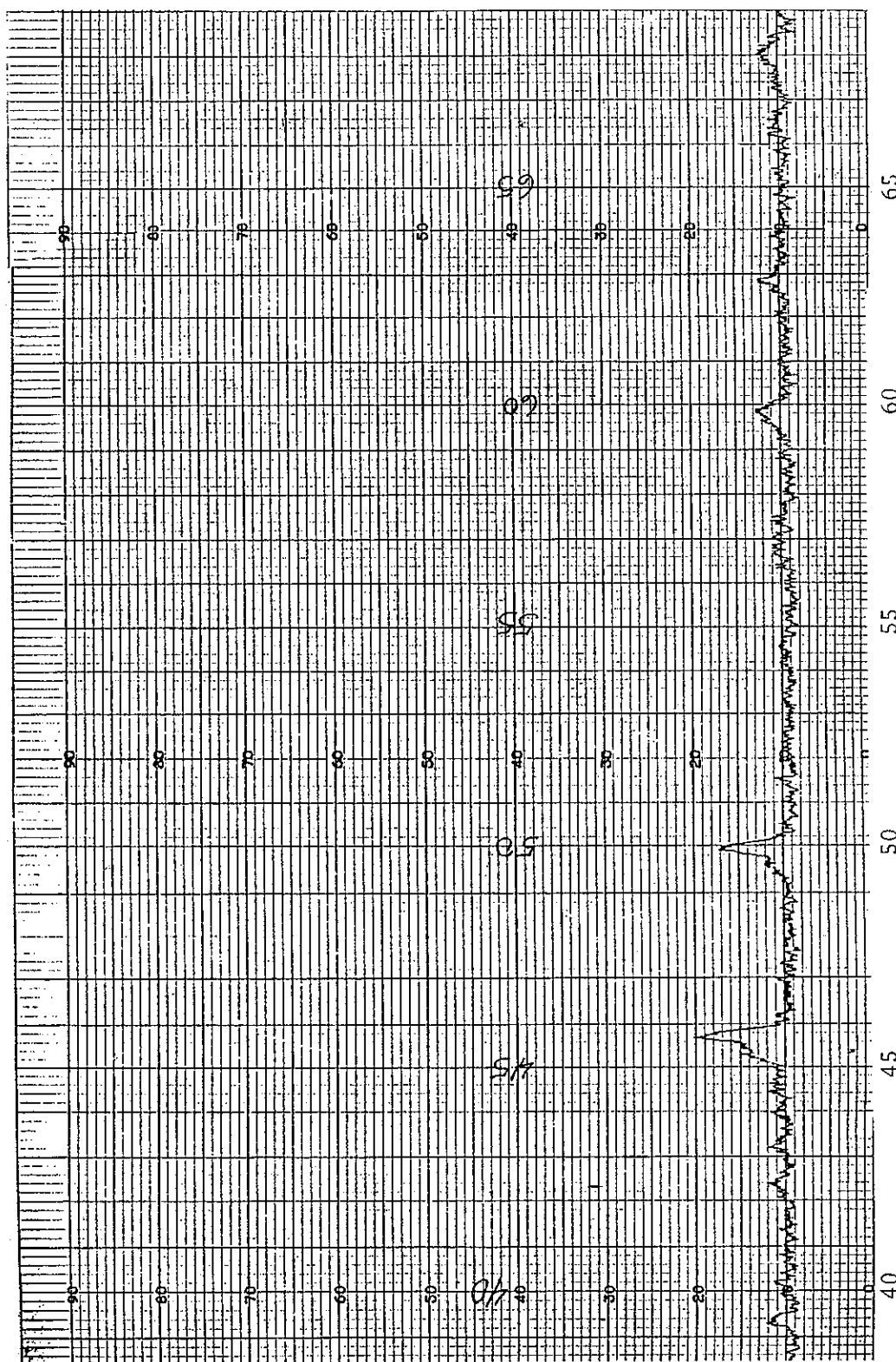


Figure 5, Part B. XRD PATTERN OF ECOMELT SHOWING AMPHOROUS PHASE

Testing and Evaluation of Blended Cement

The blended cement produced from the contaminated siliceous concrete (Test 5) was analyzed for oil, total chromium, and chromium leachability (TCLP). The blended cement product was also evaluated for compressive strength per ASTM specifications C 595 and C 1157.

Organic (Oil) Destruction

The Ecomelt as well as the blended cement were analyzed for the petroleum hydrocarbon (oil) content using GC/FID; the hydrocarbon contents were 6 and 2 ppm, respectively. This concentration was determined using the contaminating oil as a reference. The amount of oil added in the concrete prior to the testing was 5000 ppm (i.e., 0.5 wt %). Therefore, the results represent an oil destruction of 99.9% in the ground Ecomelt (further accuracy was limited due to the analytical procedure limitations). No oxygen was fed to the melter during the test; feeding some oxygen may further increase the destruction efficiency.

Metal Immobilization

The total chromium (Cr) content in the blended cement was measured to be 380 mg/kg (Table 5). The metal leachability of the blended cement was determined per the EPA TCLP procedure 1311; the chromium was present at 0.097 mg/L in the leachate, which is significantly below the regulatory leachability limit of 5 mg/L. This demonstrates that the chromium is locked into the cement matrix to completely immobilize it, and it does not leach out. Furthermore, the TCLP test conducted here is more severe than the EPA procedure since it was conducted with a fine powder.

Compressive Strength

Using the blended cement, Ottawa sand and water, a mortar mix was prepared by CTL (the research arm of the Portland Cement Association) in accordance with the ASTM C 109 standard procedure. The amount of mixing water was adjusted to produce mortars with a flow of 110 ± 5 . The mortars were cast as 2-inch cubes, and left overnight in a moist room at ambient temperature. Thereafter, the cubes were demolded and cured in saturated lime-water solution.

**Table 5. METAL IMMOBILIZATION IN BLENDED CEMENT
PRODUCED FROM CONCRETE**

Contamination (Cr^{+3}) added to concrete = 500 mg/kg (ppm)

<u>Element</u>	<u>Cr in blended cement</u> --mg/kg--	<u>TCLP Leachate Concentration</u> -----mg/L-----	<u>TCLP Regulatory Limit</u>
Chromium	380	0.097	5

These cubes were tested for compressive strength at 3, 7, and 28-day intervals as specified by the ASTM procedure; the results are shown in Table 6. The 3-day compressive strength result is 2530 psi whereas the ASTM requirement is 1890 psi per ASTM C 595 standard and 1740 psi per ASTM C 1157 standard. The 7-day compressive strength result is 3370 psi whereas the requirement is 2900 psi per ASTM C 595 standard as well as ASTM C 1157 standard. The 28-day compressive strength result is 5475 psi whereas the requirement is 3480 psi per ASTM C 595 standard (ASTM 1157 standard specifies only 3 and 7-day strength requirements). Thus the measured 28-day strength is about 57 percent higher than the ASTM requirement. Therefore, the compressive strength of the mortar cubes significantly exceeds the ASTM requirements for blended cement (C 595, C 1157) as well as portland cement (C 150). It should be noted that the blended cement did not require use of any activator (performance enhancing additive) to yield these high strengths. The results presented are the average of three separate strength tests for each time period. The reported compressive strength for the 3-day period is an average of 2463, 2638, and 2488 psi; the reported strength for the 7-day period is an average of 3350, 3330, and 3425 psi; the reported strength for the 28-day period is an average of 5463, 5305, and 5655 psi.

**Table 6. COMPRESSIVE STRENGTH OF BLENDED CEMENT
PRODUCED FROM CONCRETE**

Test Period --days--	Concrete- Based Blended Cement	ASTM Requirements		
		Blended Cement		Portland Cement
		C 595	C 1157	C 150
		-----psi-----		
3	2530	1890	1740	1740
7	3370	2900	2900	2760
28	5475	3480	NS*	4060

*NS = not specified.

ACHIEVEMENT OF PROGRAM SUCCESS CRITERIA

The following criteria were established to measure success of this research program:

- Contaminated concrete to be treated by the Cement-Lock Technology (to destroy organics and immobilize metals) must not consume fresh modifiers more than 50 weight percent of the concrete.
- Blended cement produced from the contaminated concrete must pass the EPA TCLP test for appropriate priority metals.
- Compressive strength of blended cement produced from contaminated concrete must pass ASTM Standards for blended cement.

In this program, the following were demonstrated:

The Cement-Lock Technology is suitable for treatment of contaminated siliceous as well as calcareous concrete. As shown in Table 4, the fresh modifiers used for the siliceous and calcareous concretes were 27.9 and 26.6 weight percent of the concrete, respectively (i.e., significantly less than 50 weight percent of the concrete).

The total chromium present in the blended cement was 380 mg/kg (ppm). The EPA TCLP procedure conducted on the blended cement showed the amount leached from the blended cement was only 0.097 mg/L in the leachate (see Table 5), which is significantly below the regulatory limit of 5 mg/L for chromium. This demonstrates that the metals present in the contaminated concrete can be immobilized in the final product.

The 3, 7, and 28-day compressive strengths of the blended cement were greater than those required for general purpose cement (per ASTM C 595, C 1157, and C 150 specifications). The 28-day strength was about 57 percent higher than the ASTM requirements (see Table 6). It is significant to note that these strengths were achieved without using any activators (performance enhancing additives).

The above results firmly establish that the current program was successful. The technology is now ready for the next step - the pilot-scale demonstration.

IMPACT OF TECHNOLOGY SCALE-UP ON DESTRUCTION AND REMOVAL EFFICIENCY

Thus far, the Cement-Lock Technology has been tested on a scaled-up basis with dredged sediments from the Newtown Creek (New York) estuary only. Continuous operation of the Cement-Lock Technology was achieved in an integrated pilot plant facility at feed rates averaging one ton of untreated sediments per day. The impact of scale-up on the destruction and removal efficiency (DRE) of organic contaminants, metals leachability (TCLP), and compressive strength are presented in Tables 7, 8, and 9, respectively. Table 7 shows the DRE of organic contaminants and Table 8 shows the results of TCLP analysis for the blended cements produced from the bench-scale tests and the pilot-scale test. Table 9 indicates that the strength of the cement also improved in the pilot-scale processing. Therefore, it can be concluded that there is no significant impact of the technology scale-up on the DRE of the organic contaminants, metal leachability, and product quality for contaminated estuarine sediments. A similar trend is expected from the treatment of contaminated concrete.

Table 7. COMPARISON OF ORGANIC DESTRUCTION IN BENCH-SCALE AND PILOT-SCALE UNITS FOR DREDGED ESTUARINE SEDIMENTS
(Newtown Creek Estuary Sediments)

Contaminant	Untreated Sediments		Blended Cement		DRE*	
	Lab-Scale	Pilot-Scale	Lab-Scale	Pilot-Scale	Lab-Scale	Pilot-Scale
	-----mg/kg (dry)-----		-----mg/kg (dry)-----		-----%-----	
PAHs	116	370	0.3	0.22	99.24	99.93
	-----µg/kg (dry)-----		-----µg/kg (dry)-----			
PCBs	5,270	8,585	0.75	< D.L.**	> 99.96	> 99.99
	-----ng/kg (dry)-----		-----ng/kg (dry)-----			
2,3,7,8-TCDD/TCDF	381	262	< D.L.	< D.L.	> 99.99	> 99.99
Total TCDD/F	2,620	2,871	< D.L.	< D.L.	> 99.99	> 99.99
Total PeCDD/F	3,231	4,363	< D.L.	< D.L.	> 99.99	> 99.99
Total Hx/Hp/OCDD/F	38,945	34,252	18	< D.L.	99.88	> 99.99

* Destruction and removal efficiency.

** Less than the detection limit of the analytical procedure used.

Table 8. COMPARISON OF TCLP RESULTS ON BLENDED CEMENT PRODUCED IN BENCH-SCALE AND PILOT-SCALE UNITS FROM DREDGED ESTUARINE SEDIMENTS
(Newtown Creek Estuary Sediments)

Metal	Untreated Sediments		Blended Cement		Regulatory Limit
	Lab-Scale	Pilot-Scale	Lab-Scale	Pilot-Scale	
	-----mg/kg (dry)-----		-----mg/L-----		
Arsenic	33	39	< 0.1**	< 0.005	5
Barium	--	--	< 0.5	--	100
Cadmium	37	27	< 0.01	< 0.001	1
Chromium	377	298	0.2	0.15	5
Lead	617	542	< 0.05	< 0.002	5
Mercury	1.3	2.9	< 0.001	< 0.0004	0.2
Selenium	< 3.2	6.2	< 0.1	< 0.003	1
Silver	18	13	< 0.01	< 0.001	5

* Toxicity Characteristic Leaching Procedure.

** Less than the detection limit of the analytical procedure used.

**Table 9. COMPARISON OF COMPRESSIVE STRENGTH OF BLENDED CEMENT
PRODUCED IN BENCH-SCALE AND PILOT-SCALE UNITS FROM DREDGED
ESTUARINE SEDIMENTS**
(Newtown Creek Estuary Sediments)

<u>Test Period</u>	<u>Blended Cement</u>		<u>ASTM Requirements</u>		
			<u>Blended Cement</u>		<u>Portland Cement</u>
	<u>Lab-Scale</u>	<u>Pilot-Scale</u>	<u>C 595</u>	<u>C 1157</u>	<u>C 150</u>
--days--			psi		
3	1950	2230	1890	1740	1740
7	2730	2885	2900	2900	2760
28	4620	5270	3480	NS*	4060

*NS = not specified.

ENVIRONMENTAL IMPACT

This section discusses some of the anticipated environmental, health, and safety concerns that could arise during Cement-Lock plant operations for treating contaminated concrete.

Based on the bench-scale tests, concrete treated by the Cement-Lock process is fully expected to meet all applicable regulatory requirements of the U.S. EPA. The most significant test and stabilization criteria that must be met by the Cement-Lock product is the EPA Toxicity Characteristic Leaching Procedure (TCLP; EPA Method 1311). Since the Cement-Lock Technology combines melting/vitrification with the production of cement to immobilize toxic metals, product from the Cement-Lock Technology is expected to meet the current and proposed EPA rules.

The Cement-Lock process itself is free of nuisance odors, noise, and occupational exposure hazards.

The final form in which the contaminants originally present in the concrete will ultimately exit the Cement-Lock plant are summarized in Table 10. None of these streams are hazardous, or of long-term concern for the environment. All of the streams emanating from the process can be used or disposed of immediately.

Table 10: FATE OF CONCRETE CONTAMINANTS IN CEMENT-LOCK PROCESS

Contaminant	Fate
Toxic Metals (if present): Ba, Cd, Cr, Cu, Pb, Ni, Ag, Se, Zn	Cement, stable
As, Hg	Adsorbed, solidified, and immobilized ¹
Polynuclear Aromatic Hydrocarbons, Organochlorine Pesticides, 2,3,7,8-Chlorine Substituted PCDD/PCDF Isomers:	
Organic Hydrogen	Demineralized water ²
Cl, SO _x	Salts, solidified, stable, some SO _x in off gas ³
Organic Nitrogen	Oxides of nitrogen, N ₂ ³ (off-gas)
Organic Carbon	CO ₂ (off-gas)

1 Elements could be recovered.

2 Demineralized water is free released.

3 SO_x and NO_x expected to be within regulatory limits.

TRANSITION OF TECHNOLOGY FROM BENCH-SCALE TO FULL-SCALE OPERATION

The transition of the Cement-Lock Technology for a new feedstock from bench-scale to a full-scale operation occurs in two stages. These stages are:

- Pilot Plant, which will process 5 to 10 tons of concrete in a fully integrated system, replicating a commercial system. The pilot-plant data will be used for scale-up design as well as for obtaining permits. This facility is available and is described below.
- Full-scale facility is a modular facility consisting of one or several modules of approximately 100,000 tons of concrete per year capacity. All the equipment needed for installing a full-scale plant are already available commercially.

Description of Pilot-Scale Facility

The Cement-Lock Technology has been demonstrated in both bench-scale and pilot-scale equipment with dredged sediments from the Newtown Creek estuary in New York. The tests demonstrated the effectiveness of the technology for decontaminating sediments and at the same time producing a valuable, salable product, blended cement. Laboratory-scale tests have also been conducted with contaminated river sediments as well as contaminated concrete (this report) to convert them to blended cement.

This section describes in detail the existing pilot plant facilities (as used for the sediments treatment) that are available to ENDESCO, Cement-Lock Group, L.L.C., and IGT for conducting a demonstration with contaminated concrete. The rotary kiln-type Ecomelt generator, used for the pilot-scale testing of the Cement-Lock Technology, was built by ABB Combustion Engineering. This pilot plant can easily be modified to process other contaminated materials.

The pilot plant facilities are located in Golden, Colorado. The feed capacity of the pilot plant is in the range of 100 to 300 pounds per hour, depending on moisture content of the feed material. The pilot plant (Figure 6) consists of four sections: a Denver Holoflite conveyor heated with a hot oil system for pre-drying the feed material, a 2-foot-diameter by 6.5-foot-long refractory-lined rotary kiln, a 21-inch-diameter by 24-foot-long refractory-lined secondary combustion

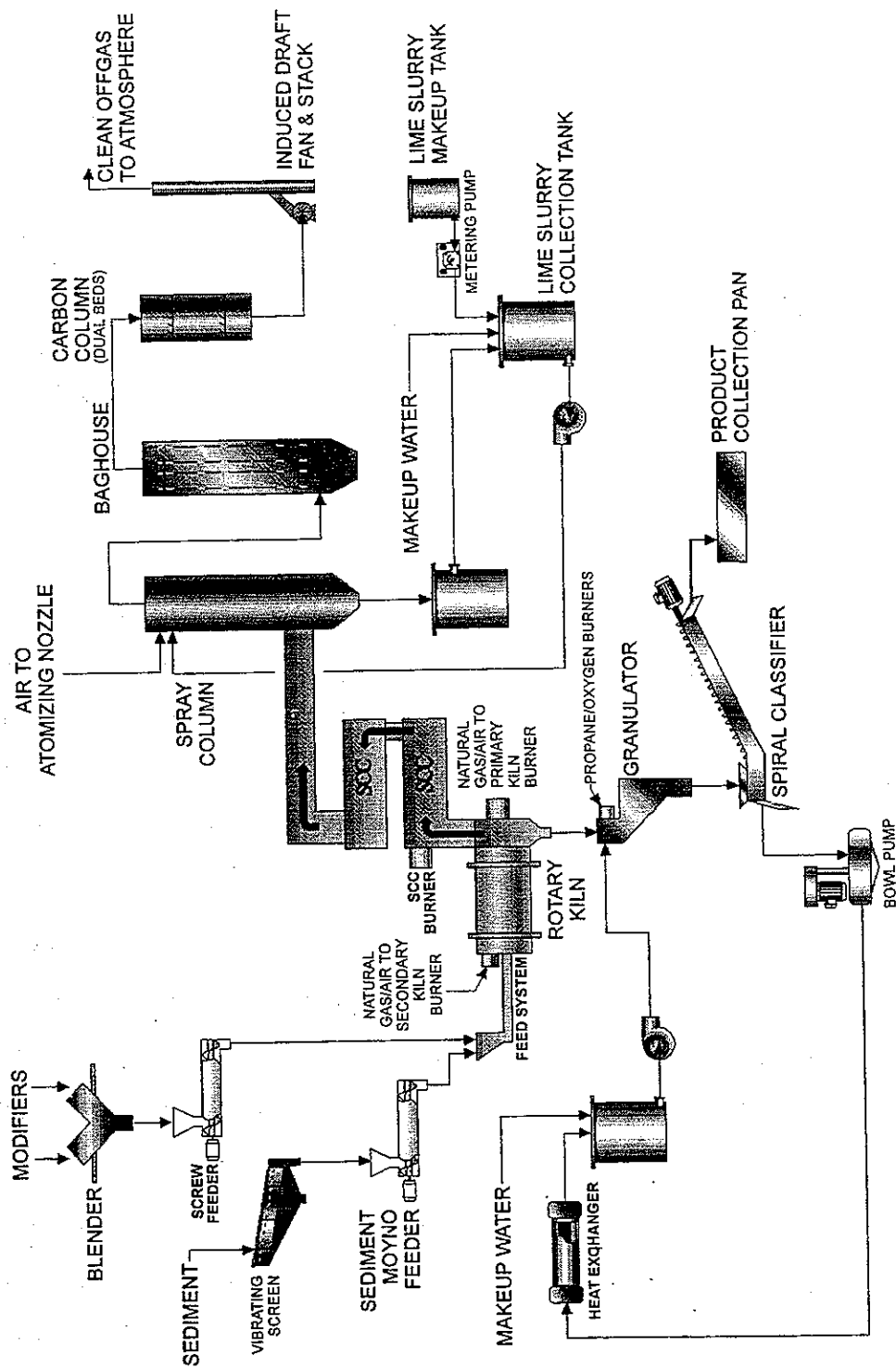


Figure 6. PROCESS FLOW DIAGRAM OF CEMENT-LOCK PILOT PLANT

chamber (SCC), and a gas-emission treatment system consisting of a quench tower for cooling the gas with a lime solution, a fabric-filter baghouse for dust control, and a two-bed absorption column for final emission control. The SCC is divided into two separate 12-foot-long sections on a horizontal plane. A draft fan provides vacuum control throughout the system.

The pilot plant is instrumented to facilitate control and to generate design data. System instrumentation includes:

- Six thermocouples which measure temperature in the kiln, SCC, quench tower, baghouse, and absorption column
- Temperature controllers which regulate air and natural gas flow to the burner systems
- Magnehelic gauges which measure pressure throughout the system and indicate differentials across orifice meters to measure air and natural gas flows
- A continuous emission monitor (CEM) which measures O₂, CO₂, CO, SO₂, O₂, NO_x, and total hydrocarbons (THC) in the SCC exhaust gas.

A Denver Equipment D0710-4 Holoflite is used to predry the feed material and flux prior to discharging to the kiln screw feeder (This step is generally not necessary). The vapors from the predrier are vented into the SCC. The Holoflite is heated with a hot-oil boiler maintained at 400°F.

The kiln is lined with monolithic casting of Ultra Green 57 A, manufactured by A. P. Green. This refractory is an ultra-low cement, 57% alumina castable with an andalusite base for thermal shock resistance, and is suitable for temperatures up to 3,000°F. The casting is poured over a one-inch-thick layer of 1,900°F insulating board to reduce heat flow to the steel shell and is secured to the kiln shell with stainless steel anchors. The casting includes a dam six inches wide by two inches high on the feed end and a dam four inches wide by one inch high on the discharge end. The kiln's inside diameter is 2.08 feet, and the internal length is 6.5 feet.

The kiln is heated using the primary natural-gas-fired burner located opposite the feed end. A secondary natural-gas-fired burner located above the kiln feeder is used to reach the high temperatures needed to melt the feed and flux materials in the kiln. The hot combustion gases generated by the burners are used to heat the dense refractory lining and the burden in the kiln. Combustion gases and any volatile matter released from the material in the kiln enter the SCC. The SCC is heated with a natural-gas-fired burner located directly past the kiln exhaust.

Hot gases and entrained solids from the SCC are quenched in a tower 21 inches in diameter by 7.5 feet in height. A recirculating lime solution is used to cool the gases in the quench tower. The pH of the solution is controlled by addition of a lime slurry to the recirculating lime solution tank. The cooled gases, at about 350°F, are filtered in a fabric-filter baghouse with a total surface area of 184 square feet. The clean gas is conveyed to a two-bed absorption column. Gas flow through the absorption column is downward. The beds are three feet in diameter and one foot deep. The beds are supported with a 14-mesh stainless steel screen on top of one-inch bar grating. The first bed contains pelletized Sorbalit® and the second bed contains American Norit R-1540 extruded activated-carbon pellets. The Sorbalit®, which is quite dusty, is placed upon about a one-inch layer of 3/8-inch ceramic balls placed on top of the screen, to minimize dust penetration into the carbon bed. The gases are vented to the atmosphere with an induced-draft fan. A manually controlled damper is used to maintain the required pressures in the system.

Process gases at the SCC exhaust duct are sampled and analyzed continuously for O₂, CO₂, CO, SO₂, NO_x, and THC. The gas sample is filtered and cooled to remove entrained particulate matter and water vapor before the gas enters the analyzer. The THC analyzer receives a filtered hot sample.

The sediments and flux are introduced into the kiln using a standard-pitch, variable-speed screw auger six inches in diameter and five feet long. The screw flights are kept full of material during operation to prevent air infiltration into the kiln through the flights.

The sediments are metered into the screw feeder hopper with a Robbins and Myers open-throat 2JS3 progressive cavity Moyno pump. In order to protect the pump, the sediment is screened at 1/4-inch using an 18-inch vibrating Sweco screen that discharges directly into the throat of the Moyno pump. Tramp materials like wood, stone, and plastic are picked off the screen. The modifiers and flux material are pre-blended before metering the blend into the screw feeder hopper, using a four-inch standard-pitch screw feeder.

A refractory-lined box, 18 inches long and with a 12-inch-square inside opening, is placed between the kiln discharge and the granulator. Propane/oxygen burners are positioned inside the box to provide a heat shield between the kiln discharge and the granulator. These burners are used to prevent the molten slag from freezing before the slag reaches the cold-water sprays inside the

granulator. The granulated product is collected in an open-trough inclined screw and conveyed onto a pan on the operation deck. The product discharge of the granulator is submerged in water to provide a seal which prevents ambient air from entering the kiln discharge. Two high-velocity water spray nozzles inside the granulator are used to quench and granulate the molten slag as it drips from the kiln discharge. A 1/2-inch pipe with seven 3/16-inch holes along one side is used to flood the sloped bottom of the granulator with additional water. The quench water overflows the screw trough into a bowl pump. The water is cooled in a heat exchanger and recirculated.

The gas composition, kiln temperature, and two SCC temperatures are logged using a MOLYTEK data-acquisition system. All other data are manually recorded hourly on data log sheets, and notes on operations and problems are recorded in an operations logbook.

Any equipment needed for a pilot-scale demonstration with concrete can easily be added to the existing pilot plant.

Existing/Operating Large-Scale Facilities

One configuration of the Ecomelt generator/melter that can be used for producing molten Ecomelt from the concrete is a vertically oriented, refractory-lined cylinder. The Type "A" melter is constructed with water-wall cooling to minimize refractory thickness. A layer of frozen slag coats the internal walls of the melter to extend refractory life. The concrete and modifiers are fed into the melter through a port at the top of the melter. The energy required to melt the concrete and modifiers is supplied through a submerged lance, which is comprised of concentric tubes for feeding air and natural gas into the melt. The lance can be moved up or down depending upon the depth of the melt. Typically, air (or enriched air) is fed through the outer shell of the lance thereby cooling the lance somewhat. Natural gas is fed through the inner tube. Combustion products bubble vigorously throughout the melt. The flow of gas instills a circulating pattern through the melt ensuring complete mixing. During initial melter operation, the lance becomes coated with a layer of frozen slag, which significantly extends its life. When a lance must be replaced, however, a spare can be installed within about 30 minutes with minimal effort.

Such a reactive melter has been developed by Ausmelt Technology Corporation, and has been deployed in numerous commercial-scale applications in the metals smelting and processing industry. A list of applications, plant capacity, location, and plant status are presented in Table 11.

Table 11. COMMERCIAL EXPERIENCE WITH TYPE “A” ECOMELT GENERATOR

Unit Capacity, ton/year	Location	Application	Status
7,500	Australia	Copper smelting	Pilot plant operation
15,000	The Netherlands	Tin smelting	Closed due to low metal price
105,000	Australia	Fuming ISF slag to produce Zn/Pb product	Operative
90,000	South Korea	Fuming Pb and Zn slag	Operative
30,000	Peru	Tin concentrate metallization	Operative
10,500	Zimbabwe	Copper, Pt-group metals	Operative
125,000	South Korea	Zn recovery from minerals	Operative
90,000	Germany	Primary and secondary Pb	In progress
120,000	Namibia	Primary Pb furnace	In progress

A second type of Ecomelt generator is based on rotary kiln; this generator has been used extensively in the past for a myriad of different applications including incineration and thermal desorption. ABB Combustion Engineering and Svedala have a long list of previous applications with rotary kiln installations (Tables 12 and 13, respectively). The pilot-scale test with dredged estuarine sediments was conducted recently in a rotary kiln operating in slagging mode.

Table 12. RAYMOND™ ROTARY KILN SYSTEMS

CUSTOMER	EQUIPMENT	WASTE	THERMAL
BORG AUSTRAL BUENOS AIRES ARGENTINA 1996	MODEL 500 ROTARY KILN WITH FEED AND ASH SYSTEM, SCC, APC, FAN, STACK, CEM MODULAR INCINERATOR	RCRA AND TSCA COMMERCIAL WASTE	6.5 MMBTU/HR, KILN 5 MMBTU/HR, SCC
CALIFORNIA THERMAL TREATMENT SYSTEMS CALIFORNIA, U.S.A. 1986	DESIGN AND ENGINEERING NO.12 ROTARY KILN, SCC, FEED SYSTEM, ASH REMOVAL APC, FAN, STACK, AND TANKS. RCRA PERMIT RECEIVED. BUILDING PERMIT DENIED. PROJECT CANCELLED.	RCRA AND TSCA COMMERCIAL WASTE	30 MM BTU/HR, KILN 20 MM BTU/HR, SCC
CHEM-SECURITY CANADA 1990	NO.9 ROTARY KILN WITH FEED AND ASH SYSTEM, SCC, APC, FAN, AND STACK	RCRA AND TSCA COMMERCIAL WASTE	25 MM BTU/HR, KILN 15 MM BTU/HR, SCC
CHEMICAL WASTE MGMT TEXAS, U.S.A. 1989	MATERIAL HANDLING SYSTEM FOR THE ROTARY INCINERATOR	RCRA AND TSCA COMMERCIAL WASTE	NOT APPLICABLE
EASTMAN KODAK NEW YORK, U.S.A. 1994	SCC WITH BURNER SYSTEM AND EMERGENCY STACK	WASTE GAS	22 MM BTU/HR
ELI LILLY INDIANA, U.S.A. 1984	SCC, BURNER SYSTEM, EMER. STACK, AND GAS QUENCH	WASTE GAS	25 MM BTU/HR
ENVIROPACE HONG KONG 1991	NO.10 ROTARY KILN WITH SHREDDER, FEED AND ASH SYSTEM, SCC, BOILER, APC, FAN, AND STACK	RCRA AND TSCA COMMERCIAL WASTE	30 MM BTU/HR, KILN 36 MM BTU/HR, SCC
GENERAL MOTORS KANSAS, U.S.A. 1980	NO.5 ROTARY KILN WITH FEED AND ASH SYSTEM, SCC, APC, FAN, AND STACK	PAINT SLUDGE PLANT TRASH	3 MM BTU/HR, KILN 2 MM BTU/HR, SCC
HOUSTON CHEMICAL TEXAS, U.S.A. 1991	NO.15 ROTARY KILN WITH FEED SYSTEM, AND ASH REMOVAL. PROJECT ON HOLD	RCRA AND TSCA COMMERCIAL WASTE	90 MM BTU/HR, KILN
INDUSTRIAL SERVICE CORP. MISSOURI, U.S.A. 1986	NO.9 ROTARY KILN, SCC, FEED SYSTEM, ASH REMOVAL, APC, FAN, STACK, AND TANKS. EQUIPMENT BUILT, BUT PERMIT DENIED, PROJECT CANCELLED	RCRA AND TSCA COMMERCIAL WASTE	25 MM BTU/HR, KILN 15 MM BTU/HR, SCC

Table 12 (Cont.). RAYMOND™ ROTARY KILN SYSTEMS

CUSTOMER	EQUIPMENT	WASTE	THERMAL
MONSANTO (MPKC) THAILAND 1994	NO.6 ROTARY KILN WITH FEED AND ASH SYSTEM, SCC, APC, FAN, AND STACK	ABS PLASTICS, PLANT TRASH	12 MM BTU/HR. KILN 5 MM BTU/HR. SCC
NISSAN MOTORS TENNESSEE, U.S.A. 1987	NO.7 ROTARY KILN WITH FEED AND ASH SYSTEM, SCC, BOILER, APC, FAN, STACK, AND TANKS	PAINT SLUDGE, PLANT TRASH	15 MM BTU/HR. KILN 15 MM BTU/HR. SCC
PEOPLES REPUBLIC OF CHINA JINZHOU, CHINA 1985	NO.9 ROTARY KILN WITH FEED AND ASH SYSTEM, BOILER, SCC, APC, FAN, AND STACK	MOTOR OIL FILTRATE	25 MM BTU/HR. KILN 15 MM BTU/HR. SCC
ROSS ENVIRONMENTAL OHIO, U.S.A. 1984	NO.10 ROTARY KILN AND INLET HEAD	RCRA COMMERCIAL WASTE	40 MM BTU/HR. KILN
U.S.A. DEPARTMENT OF AGRICULTURE MEXICO 1981	NO.6 ROTARY KILN WITH FEED AND ASH SYSTEM, BOILER, SCC, APC, FAN, AND STACK	BIOLOGICAL WASTE	6 MM BTU/HR. KILN 0.5 MM BTU/HR. SCC
CONFIDENTIAL 1988	NO.7 ROTARY KILN WITH FEED AND ASH SYSTEM, SCC, APC, FAN, AND STACK MOBILE INCINERATOR	RCRA AND TSCA COMMERCIAL WASTE	15 MM BTU/HR. KILN 15 MM BTU/HR. SCC
CONFIDENTIAL 1994	NO.12 ROTARY KILN WITH CYCLONE, AND SCC	SOILS	70 MM BTU/HR. KILN 110 MMBTU/HR. SCC
CONFIDENTIAL 1996	MODEL 500 ROTARY KILN WITH FEED AND ASH SYSTEM, SCC, APC, FAN, STACK, AND PLUME SUPPRESSION SYSTEM MODULAR INCINERATOR	RCRA COMMERCIAL WASTE	6.5 MMBTU/HR. KILN 5 MMBTU/HR. SCC
CONFIDENTIAL 1996 EUROPE	NO. 9 ROTARY KILN WITH FEED AND ASH SYSTEMS. WITH ABB SUPPLIED WASTE HEAT RECOVERY BOILER, MULTI STAGE DRY SCRUBBER, PLC AND SCADA SYSTEM.	PHARMACEUTICAL WASTE	25 MMBTU/HR. KILN 15 MMBTU/HR. SCC

Table 12 (Cont.). RAYMOND™ ROTARY KILN SYSTEMS

CUSTOMER	EQUIPMENT	WASTE	THERMAL (TOTAL)
ALLEN BRADLEY	ROTARY KILN	METAL SLUDGE	5 MM BTU/HR
AMOCO CHEMICAL	ROTARY KILN, SCC, APC	TPA RESIDUE	(2) - 60 MM BTU/HR
AMOCO CHEMICAL	ROTARY KILN, SCC, APC	CHEMICAL WASTE	1 MM BTU/HR
BASRAH PETROCHEM	ROTARY KILN, SCC, APC	PLASTIC BIO SLUDGE	5 MM BTU/HR
BETHLEHEM STEEL	ROTARY KILN	METAL SLUDGE	5 MM BTU/HR
CHEMICAL WASTE MGMT	ROTARY KILN	HAZARDOUS WASTE	60 MM BTU/HR
CITY OF CHICAGO	ROTARY KILN	MSW	(3) - 80 MM BTU/HR
CITY OF CINCINNATI	ROTARY KILN	MSW	60 MM BTU/HR
CITY OF LOUISVILLE	ROTARY KILN, SCC, APC	MSW	30 MM BTU/HR
DOW CHEMICAL	ROTARY KILN	LL RAD. WASTE	40 MM BTU/HR
EASTMAN KODAK	ROTARY KILN	SEWAGE SLUDGE	50 MM BTU/HR
E. I. DUPONT	ROTARY KILN, SCC	CHEMICAL WASTE	5 MM BTU/HR
ELI LILLY	ROTARY KILN, SCC	PHARMACEUTICALS	60 MM BTU/HR
ENGLEHARDT	ROTARY KILN, SCC, APC	METAL SLUDGE	40 MM BTU/HR
FLUOR CORP.	ROTARY KILN	CHEMICAL WASTE	40 MM BTU/HR
HARSHAW CHEMICAL	ROTARY KILN, SCC, APC	CHEM & METAL SLUDGE	(2) - 30 MM BTU/HR
M & T CHEMICAL	ROTARY KILN, SCC, APC	METAL SLUDGE	10 MM BTU/HR
3 M COMPANY	ROTARY KILN, SCC, APC	CHEMICAL WASTE	(2) - 25 MM BTU/HR
MORTON FOODS	ROTARY KILN, SCC, APC	SLUDGES	5 MM BTU/HR
PP&G	ROTARY KILN, SCC, APC	CHEMICAL WASTE	15 MM BTU/HR
RADFORD ARSENAL	ROTARY KILN	MILITARY WASTE	15 MM BTU/HR
RADFORD ARSENAL	ROTARY KILN	MILITARY WASTE	5 MM BTU/HR
RICHARDSON-MERRELL	ROTARY KILN, SCC, APC	BIOLOGICAL WASTE	3 MM BTU/HR
ROLLINS ENVIRONMENTAL	ROTARY KILN	HAZARDOUS WASTE	(3) - 60 MM BTU/HR
SOUTH DADE COUNTY	ROTARY KILN, SCC, APC	MSW, MEDICAL	40 MM BTU/HR
SUNFLOWER ARSENAL	ROTARY KILN, SCC, APC	ROCKET PROPELLANT	10 MM BTU/HR

Table 12 (Cont.). RAYMOND™ ROTARY KILN SYSTEMS

CUSTOMER	EQUIPMENT	WASTE	THERMAL (TOTAL)
TRANS ALASKA CORP.	ENGINEERING ONLY	OIL & DRILLING SLUDGE	40 MM BTU/HR
TENNESSEE EASTMAN	ROTARY KILN, SCC, APC	CHEMICAL WASTE	40 MM BTU/HR
U.S. NAVY	ROTARY KILN, SCC, APC	TANK BOTTOMS, SOLVENTS	5 MM BTU/HR
WALLOVER OIL	ROTARY KILN, SCC, APC	DIATOMACEOUS EARTH	2 MM BTU/HR
WYANDOTTE CHEMICAL	ENGINEERING ONLY	CHEMICAL WASTE	2 MM BTU/HR

Table 13. SVEDALA ROTARY KILN SYSTEMS

	PROJECT/CUSTOMER	YEAR	WASTE TYPE	TYPE OF EQUIPMENT	HEAT RELEASE/ PRIMARY- SECONDARY		COMMENTS
1	WEST VIRGINIA PULP & PAPER	1965	CHEMICAL WASTES	ROTARY KILN 15 X 80	145 MMBTU/HR	EQUIPMENT SUPPLY	
2	WEST VIRGINIA PULP AND PAPER	1966	CHEMICAL WASTES	ROTARY KILN 15 X 80	145 MMBTU/HR	EQUIPMENT SUPPLY	
3	MONSANTO/ENVIRO-CHEM	1973	MUNICIPAL REFUSE	ROTARY KILN 20 x 100	250 MBTU/HR	EQUIPMENT SUPPLY	
4	GENERAL ELECTRIC	1979	CHEMICAL WASTES	ROTARY KILN 12.5 X 35	45 MBTU/HR	DRUM WASTE FED INTO SYSTEM	
5	ROY F. WESTON	1986	PCB SOILS	ROTARY KILN 7.5 X 25, SCC	35 MBTU/HR	TRANSPORTABLE SYSTEM/THREE SITES	
6	INTERNATIONAL TECHNOLOGY	1986	CONTAMINATED SOILS	ROTARY KILN 7.5 X 45	50 MBTU/HR	TRANSPORTABLE SYSTEM/THREE SITES	
7	DUPONT CORPORATION	1986	CONTAMINATED SOILS	ROTARY KILN 7.7 X 45	50 MBTU/HR	ON-SITE CLEANUP/TRANSPOR- TABLE SYSTEM	
8	DEPT. OF ARMY	1987	CHEMICAL WASTES	CONFIDENTIAL	CONFIDENTIAL	CONFIDENTIAL	
9	WASTE TECH SERVICES	1988	CHEMICAL WASTES	ROTARY KILN 10.5 X 30, SCC	50 MBTU/HR	FIXED PROCESS SITE	
10	DEPT. OF ENERGY	1988	URANIUM RECOVERY	CONFIDENTIAL	CONFIDENTIAL	CONFIDENTIAL	
11	McGILL ENVIRONMENTAL	1988	CHEMICAL WASTE	ROTARY KILN 9.5 X 30	50 MBTU/HR	TURNKEY TRANSPORTABLE SYSTEM	
12	ENVIRITE FIELD SERVICES	1988	CONTAMINATED SOILS	ROTARY KILN 7.5 X 45	50 MBTU/HR	TRANSPORTABLE SYSTEM	
13	McGILL ENVIRONMENTAL	1988	HAZARDOUS WASTE	ROTARY KILN 7.5 X 45	50 MBTU/HR	TRANSPORTABLE SYSTEM	
14	GLAXO CO.	1989	BIOMEDICAL WASTE	FIXED HEARTH HR 75, SCC	8 MBTU/HR	BIOHAZARDOUS/RADIOACTIVE RESEARCH	
15	DUPONT CORPORATION	1989	INDUSTRIAL WASTE	ROTARY KILN 12 X 50, SCC	60 MBTU/HR	TURNKEY SYSTEM/WASTE HEAT RECOVERY	

Table 13 (Cont.). SVEDALA ROTARY KILN SYSTEMS

	PROJECT/CUSTOMER	YEAR	WASTE TYPE	TYPE OF EQUIPMENT	HEAT RELEASE/ PRIMARY- SECONDARY	COMMENTS
16	USPCI/STEARNS	1990	CONTAMINATED SOILS	ROTARY KILN 10 X 85	40 MBTU/HR	REGIONAL COMMERCIAL FACILITY
17	USPCI/STEARNS	1990	CHEMICAL WASTES	ROTARY KILN 16 X 50	100 MBTU/HR	REGIONAL COMMERCIAL FACILITY
18	IT McGILL	1990	CONTAMINATED SOIL	ROTARY KILN 13.5 X 75	145 MBTU/HR	TRANSPORTABLE SYSTEM
19	WASTE TECH SERVICES	1991	CHEMICAL WASTES	ROTARY KILN 11 X 40, SCC	75 MBTU/HR	PETRO-CHEMICAL FACILITY
20	MERCK & CO.	1991	BIOMEDICAL WASTES	ROTARY KILN 8 X 20, SCC	10 MBTU/HR	COMPLETE SYSTEM/MULTIPLE FEED SYSTEM
21	ORTHO PHARMACEUTICAL	1992	BIOMEDICAL WASTES	ROTARY KILN 8 X 20, SCC	15 MBTU/HR	COMPLETE SYSTEM/MULTIPLE FEED SYSTEM
22	MERCK & CO.	1992	BIOMEDICAL WASTES	ROTARY KILN 10 X 35, SCC	30 MBTU/HR	COMPLETE SYSTEM/MULTIPLE FEED SYSTEM
23	IT-OHM	1992	HAZARDOUS WASTE	ROTARY KILN 13.5 X 75, SCC	145 MBTU/HR	EQUIPMENT SUPPLY
24	E. YOUNG CHEMICAL	1992	INDUSTRIAL WASTES	ROTARY KILN 12 X 50, SCC	60 MBTU/HR	PROCESS DESIGN AND EQUIPMENT SUPPLY
25	MT. SINAI MEDICAL CENTER	1992	BIOMEDICAL WASTES	ROTARY KILN 8 X 20, SCC	10 MBTU/HR	TURNKEY SYSTEM
26	CHI MEI CORPORATION	1993	INDUSTRIAL WASTES	ROTARY KILN 12.5 X 55, SCC	70 MBTU/HR	COMPLETE SYSTEM
27	MITSUHIRAKAWA GUIDOM	1994	INDUSTRIAL WASTES	ROTARY KILN 5' X 15'	2.7 MBTU/HR	TEST KILN FOR JAPAN
28	ANDERSON 2000	1995	HAZARDOUS WASTES	ROTARY KILN 11.5' X 30'	25 MMBTU/HR	EQUIPMENT SUPPLY
29	DANISH WASTE MANAGEMENT	1995	HAZARDOUS WASTES	ROTARY KILN 11' X 40'	55 MBTU/HR	COMPLETE SYSTEM

COMMERCIALIZATION OF CEMENT-LOCK TECHNOLOGY

Because of the importance of the Cement-Lock Technology, IGT's subsidiary, ENDESCO Services, Inc. is assembling the following, well-experienced team to accomplish the ambitious goals of all commercial projects in an expeditious and cost-effective manner. The team includes the following:

- ◆ Cement-Lock Group, L.L.C. – the licensor of the Cement-Lock Technology
- ◆ Institute of Gas Technology (IGT) – the research arm of the Cement-Lock Group, L.L.C., and developer of the technology
- ◆ an A&E (architecture and engineering) firm that will be selected from the list of Roy F. Weston, Metcalf and Eddy, Bechtel, Dames & Moore, and Foster Wheeler Environmental
- ◆ Equipment manufacturer that will be selected from Svedala, ABB Combustion Engineering, Ausmelt Technology Corporation, or other
- ◆ a plant construction company
- ◆ a cement manufacturer or a ready-mix company to sell the product in the marketplace
- ◆ Construction Technology Laboratories, Inc. – the research arm of the Portland Cement Association.

Technology transfer will be provided by Cement-Lock Group, L.L.C. IGT will provide overall technical support during the plant design stages as well as the initial plant operation. Construction Technology Laboratories will provide support for cement testing and certification. ENDESCO will manage planning and execution of the construction and operation of the entire facility and will also act as the primary contact for the vendor.

ENDESCO Services, Inc., a wholly owned subsidiary of the Institute of Gas Technology, is located in Des Plaines, Illinois. The corporate objective of ENDESCO is to bring technologies developed by IGT as well as third-parties into the marketplace in profitable commercial ventures. Currently, ENDESCO is actively and aggressively marketing such technologies as Cement-Lock, ACIMET (two-stage anaerobic digestion process for sewage sludge), among others.

ENDESCO and IGT have been actively pursuing the commercialization of IGT technologies for many years. They have demonstrated an exceptional commercialization track

record. Depending upon the characteristics of the technology and the appropriate marketplace, IGT will commercialize technology through new venture formation such as ENDESCO, partnerships, and technology transfer/license agreements.

Two recent examples of venture formation are:

- In 1987, IGT formed a subsidiary, M-C Power Corporation, for the purpose of manufacturing molten carbonate fuel cells for the electric power generation market based on IGT's fuel cell technology. In exchange for a license to use IGT's technology, IGT received a 51 percent ownership in M-C Power. The remaining 49 percent is equally owned by Bechtel Corporation and Ishikawajima-Harima Heavy Industries Co., Ltd. (IHI).
 1. M-C Power's role is to manufacture the fuel cells,
 2. Bechtel Corporation engineers the systems, and
 3. Stewart and Stevenson Corporation fabricates the power plants.

M-C Power is now in the demonstration phase of the full scale technology. Two demonstration programs have been completed in which 250 kW capacity complete systems were tested at utility sites. It is expected that commercial sales will begin in 2000. M-C Power now employs 75 people with a budget of \$20 to \$25 million per year.

- In 1991, IGT formed a joint venture, Shanghai Zhihai Gasification Technology Development Corp., Ltd., with Shanghai Coke and Chemical Company of the Peoples Republic of China, to design and construct coal gasification plants in China based on IGT's U-GAS technology. Eight coal gasifiers have recently been designed and constructed, and six gasifiers are now in various stages of operation.

IGT has also commercialized numerous technologies through license/partnership agreements with commercial firms (Table 14).

Table 14. COMMERCIALIZED IGT TECHNOLOGIES

IGT Technology	Licensee
<ul style="list-style-type: none"> • Oxygen Enriched-Air Staging (Glass Industry) 	<ul style="list-style-type: none"> - Combustion Tec, Inc., Apopka, FL - Air Products and Chemicals, Inc., Allentown, PA
<ul style="list-style-type: none"> • High Luminosity Burner 	<ul style="list-style-type: none"> - Combustion Tec., Inc. , Apopka, FL
<ul style="list-style-type: none"> • U-GAS® for coal gasification 	<ul style="list-style-type: none"> - Enviropower, Inc., Tampere, Finland - Shanghai Zhihai Gasification Technology Development Corp., Ltd., Shanghai, Peoples Republic of China
<ul style="list-style-type: none"> • RENUGAS® for Biomass gasification 	<ul style="list-style-type: none"> - The Pacific International Center for High Technology Research, Honolulu, Hawaii - Enviropower, Inc., Tampere, Finland
<ul style="list-style-type: none"> • Molten Carbonate Fuel Cells 	<ul style="list-style-type: none"> - M-C Power Corporation, Burr Ridge, IL - Energieonderzoek Centrum Nederland Petten, The Netherlands
<ul style="list-style-type: none"> • Microbial Desulfurization 	<ul style="list-style-type: none"> - Energy BioSystems Corporation, The Woodlands, TX
<ul style="list-style-type: none"> • ACIMET® 	<ul style="list-style-type: none"> - DuPage Group, Woodridge, IL - Convergent Biomass Technologies, Inc., Round Lake, IL
<ul style="list-style-type: none"> • Methane de-NOX® 	<ul style="list-style-type: none"> - Takuma Company Ltd., Osaka, Japan - Detroit Stocker Company, Monroe, MI
<ul style="list-style-type: none"> • Pre-mixed Cyclonic Burner 	<ul style="list-style-type: none"> - Takuma Company Ltd., Osaka, Japan - Burnham Corporation, Lancaster, PA
<ul style="list-style-type: none"> • Nozzle-Mix Cyclonic Burner 	<ul style="list-style-type: none"> - Donlee Technologies Inc., York, PA
<ul style="list-style-type: none"> • Oscillating Combustion 	<ul style="list-style-type: none"> - American Air Liquide, Countryside, IL - L'Air Liquide, S.A., Paris, France
<ul style="list-style-type: none"> • Surface Combustor/Fluid Heater 	<ul style="list-style-type: none"> - Takuma Company Ltd., Osaka, Japan
<ul style="list-style-type: none"> • High Temperature Industrial Furnace Probe 	<ul style="list-style-type: none"> - Combustion Tec, Inc. , Apopka, FL
<ul style="list-style-type: none"> • Hot-Tap Sectionalizing Valve 	<ul style="list-style-type: none"> - T.D. Williamson, Inc.

CONCLUSIONS AND RECOMMENDATIONS

Contaminated/used siliceous as well as calcareous concretes were evaluated as candidates for producing Ecomelt (a cementitious material) by melting with appropriate modifiers, to partially replace portland cement for construction purposes. The Ecomelt was then mixed with an appropriate additive to produce blended cement, which can be sold in the marketplace.

Conclusions

The following conclusions are based on the results of a series of tests conducted in a bench-scale unit:

- The Cement-Lock Technology is found to be suitable for treating contaminated siliceous as well as calcareous concrete due to its wide operating window in terms of temperature and quantity of modifiers needed. The quantity of modifiers required for this particular application is less than thirty weight percent of the concrete.
- The organic contaminant (oil) present in the concrete was destroyed in the process.
- The feed concrete was contaminated with 500 mg/kg (ppm) of chromium (III). The total chromium present in the blended cement was 380 mg/kg (ppm). The EPA TCLP procedure conducted on the blended cement showed the amount leached from the blended cement was only 0.097 mg/L in the leachate, which is significantly below the regulatory limit of 5 mg/L for chromium. This demonstrates that the metals present in the contaminated concrete can be immobilized in the final product.
- Based on its physical and chemical characteristics, about 78% concrete and only 22% inexpensive modifiers were used to generate Ecomelt of sufficient reactivity. It may be possible to further reduce the amount of modifiers required at relatively low temperatures by additional testing with the concrete.
- The blended cement contains 40 percent Ecomelt (the maximum replacement allowed by the ASTM C 595 specification) and generated 3, 7, and 28-day compressive strengths that are greater than those required for general purpose cement (per ASTM C 595, C 1157, and C 150 specifications). The 28-day strength was about 57 percent higher than the ASTM requirements. It is significant to note that activators (performance enhancing additives) were not added to the blended cement product.

The Cement-Lock Technology is now ready for a pilot-scale demonstration with contaminated concrete. Previous studies conducted at IGT with dredged estuarine sediments at

bench-scale and pilot-scale levels yielded similar results in terms of organic destruction, metals immobilization, and cement quality. Results from a pilot-scale operation with concrete are also expected to be similar to those achieved in the bench-scale testing.

The Cement-Lock process economics are also very favorable because of the dual revenue streams associated with the process: processing (tipping) fees received for the contaminated concrete and revenues received from the sale of the cement product.

Recommendations for Further Work

This study has clearly indicated that contaminated concrete can be treated and transformed into salable blended cement using the Cement-Lock Technology. The blended cement product generated 3, 7, and 28-day compressive strengths greater than those required for general purpose cement (per ASTM C 595, C 1157, and C 150 specifications). The 28-day strength was about 57 percent higher than the ASTM requirements. However, more characterization tests are required on the cement product before it can be adopted for general construction purposes. These tests include drying shrinkage, setting times, heat of hydration, air content, autoclave expansion and contraction, and sulfate resistance.

Based on the favorable experimental results achieved here as well as those with harbor sediments, it is recommended that the Cement-Lock process for contaminated/used concrete be advanced to pilot-scale demonstration.

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